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Evaluation Study

A FULLY DIGITAL PLANNING AND MANUFACTURING OF AN AESTHETICALLY CONCEIVED AND GUIDED FULL-ARCH IMPLANT-SUPPORTED REHABILITATION

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ABSTRACT

In the rapidly evolving implant dentistry scenario, integrating digital technologies has significantly advanced the precision and efficiency of treatments, especially in full arch implant-supported rehabilitations. Despite these advancements, a completely digital approach to complex cases remains difficult and very challenging, necessitating a hybrid approach that utilizes both digital and traditional techniques. This technical note delineates a combined digital workflow for aesthetically guided, full arch implant-supported rehabilitations in the upper jaw, avoiding the need for interim dentures. Integrating a precise analogical plaster implant impression, advanced digital scanning and planning, mandibular movement registration (ITAK®), and face scans are possible by detecting a reference area defined by the palatine wrinkles. This approach aims to maximize aesthetic, functional, and biomechanical outcomes and addresses the ongoing debate about the accuracy of intraoral scanner scans versus traditional impression methods for full arch restorations. Although digital methods are increasingly favored for their efficiency and potential for trueness and precision, our procedure underscores the relevance of detecting an anatomical area as a reference. Through a detailed technical note, this paper showcases a reproducible protocol that combines the effectiveness of analogic plaster impressions with the benefits of digital planning and Computer-Aided Manufacturing, representing a step towards the future of implant dentistry where digital processes may fully supplant traditional procedures for the immediate loading and the further final prosthetic restoration, enhancing patient outcomes through more accurate and efficient treatment modalities.

INTRODUCTION

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Implant dentistry has witnessed remarkable advancements driven by technological innovation and an expanding understanding of mechanical and biological aspects. The treatment of complex cases, historically challenged by anatomical constraints, prosthetic considerations, and patient expectations for functionality and aesthetics, has evolved significantly. Traditionally, rehabilitating patients presenting hopeless teeth involved creating a removable denture from an initial impression and a facebow registration. This denture, worn post-extraction, was a practical method to evaluate aesthetics, phonetics, and functional integration.

Literature reports various methods to assess the correct Vertical Dimension of Occlusion (VDO) for a patient (1), acknowledging it as an adaptability range from which clinicians choose a value to balance aesthetic and functional requirements (2). However, it is also noted that no universal, well-established rules exist for determining VDO once it is lost, mainly due to inter-patient variations (3,4). If teeth are present or a removable denture has already been fabricated and the current VDO is deemed correct, pre-extraction records have been suggested because teeth represent an index.

Digital technologies have heavily influenced how specific tasks are performed in dentistry, including full arch implant-supported restorations. As reported in a recent paper by Feng et al. (5), the traditional systems to transfer information from the dental clinic to the dental laboratory are time-consuming and prone to cumulative errors. At the same time, digital methods are faster and less prone to data modification during the transferring phase. The same Authors, in their report on a dentate patient, noted that intraoral scanners (IOS), facial scanners, 3D low-dose radiographic exams like cone beam computed tomography (CBCT), and digital dynamic occlusion registration can nowadays be blended into specific planning software to create a virtual patient and make many manual steps outdated, especially if they decide to consider the palatine wrinkles as an anatomical reference.

Given the effectiveness of digital technologies, it is possible to integrate different files derived from several digital devices into a single project due to the coupling of the same anatomical reference, even if many elements are still required to streamline the digital protocol completely. Detecting a common anatomical reference among all the different files (intraoral scans during the diagnostic phase, digital wax-up proposal, master cast derived from the plaster impression) is pivotal in a stable, reliable, reproducible information transferring among all the phases.

Moreover, despite some authors (6, 7) reporting potentially comparable results in full arch implants IOS vs. plaster impressions, many are still cautious in considering digital scans on full arch implant-supported restorations as a substitute for the current gold standard (8–10). On the other hand, some authors recently reported no significative difference when comparing computer-aided manufacturing (CAM) produced full arch frameworks derived from digital impressions with the plaster impression counterparts (11). Discrepancies in reports might be attributable to the evolution of scanning equipment, acquisition protocols, and operator experience (12, 13). Nevertheless, digital planning and CAM integration hold promise, particularly as full-arch frameworks produced via Computer Numerical Control (CNC) machining have shown greater precision than traditional casting, given that an accurate impression is provided (14).

This paper details the author's approach to digital upper jaw full arch implant-supported rehabilitations. This method exploits digital technologies to prevent the need for physical dentures and facebow registrations while maximizing integration in patient aesthetics thanks to new technologies. By creating a virtual patient, this protocol enhances treatment accuracy and capitalizes on the benefits of CAD/CAM while retaining the precision of analog plaster impressions. As digital impression precision continues to improve, this protocol represents a step towards a future where digital processes can fully replace traditional methods in implant dentistry, thereby enhancing patient outcomes through more accurate and efficient treatment modalities.

CASE REPORT

In this case study, a 38-year-old female dental-phobic patient (with a traumatic dental background and long-standing phobia regarding dental check-ups and treatments) sought dental treatment at our private practice, aiming for a fixed rehabilitation and aesthetic restoration of the hopeless upper and lower arches. The patient presented an unremarkable medical history, classifying her as ASA I, and prioritized aesthetics while expressing a desire for swift rehabilitation. She emphasized avoiding any visible void in the aesthetic zone following extractions. She sought a solution to restore her full masticatory function, which had been significantly impaired and limited to her anterior teeth.

The first clinical step aimed to gather all the relevant information for the author’s digital workflow. Extraoral, smiling, non-smiling, and intraoral photographs were acquired using a standardized protocol (Fig. 1), highlighting the lack of soft tissue support and Posterior Bite Collapse (PBC). Subsequently, a CBCT exam was acquired to gather anatomical information, primarily bone availability and maxillary sinus morphology, and a double arch digital impression, including palatine wrinkles for the upper jaw, with a virtual occlusal record was acquired as a prosthetic reference (Fig. 2).

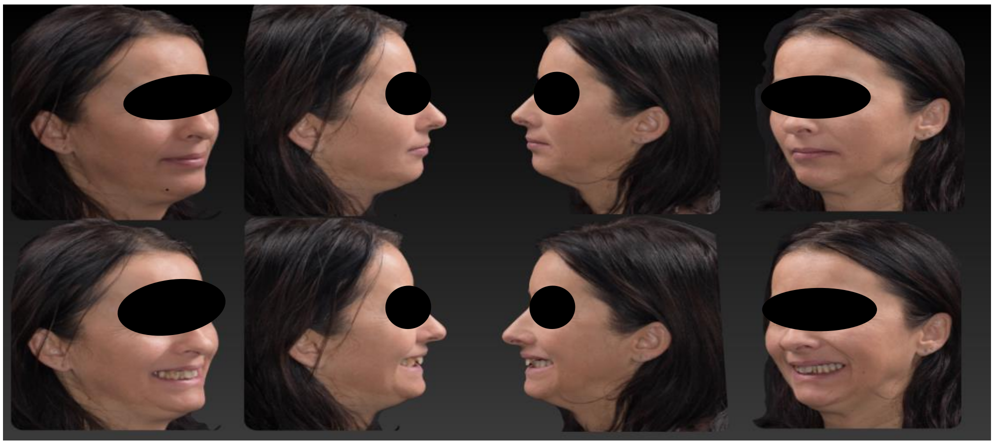

Fig. 1. *Patient panel reporting the initial extraoral condition.*

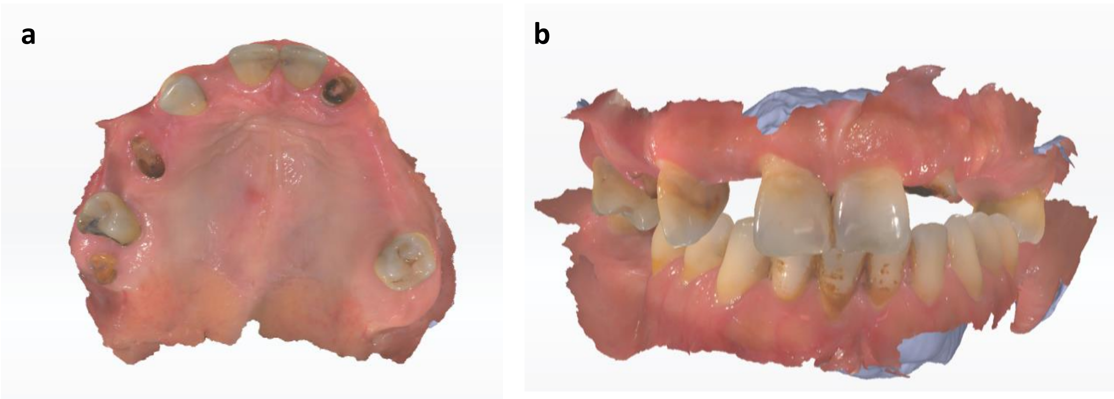

Fig. 2. *Digital scans of the individual jaws and the upper one with the palatine wrinkles (**a**) and arches articulated one another (**b**).*

During the initial consultation, a comprehensive clinical examination was carried out, revealing a significant occlusal deficiency due to the loss of multiple posterior teeth in both arches, resulting in a condition identified as PBC (Fig. 3). Given the absence of any previous records to define the patient's original occlusal schema, a detailed facial registration (MetiSmile, SHINING 3D Tech Co., Ltd., Hangzhou, China) (Fig. 4) alongside dynamic occlusion measurements, specifically called jaw kinematic analysis, (Cyclops, Itaka Way Med SRL, Marcon, Venice, Italy) were obtained (Fig. 5). A surface electromyography examination was executed (Teethan®, Teethan S.p.A, Milan, Italy) to evaluate the current occlusal schema and verify the absence of parafunctional loads. These assessments were instrumental in establishing the optimal occlusal relationship for the forthcoming rehabilitation process.

Fig. 3. *Patient's composite reporting the starting intraoral condition.*

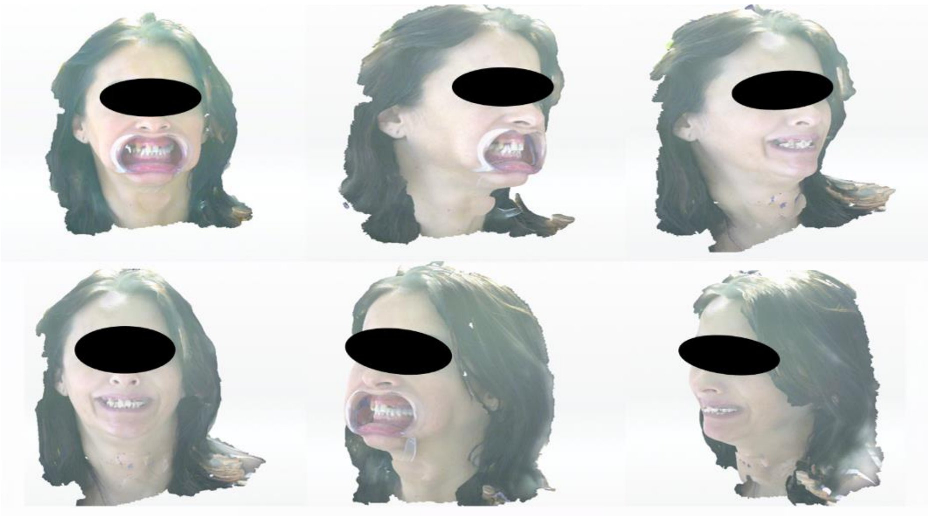

Fig. 4. *Various steps of a face scan acquisition through MetiSmile's software.*

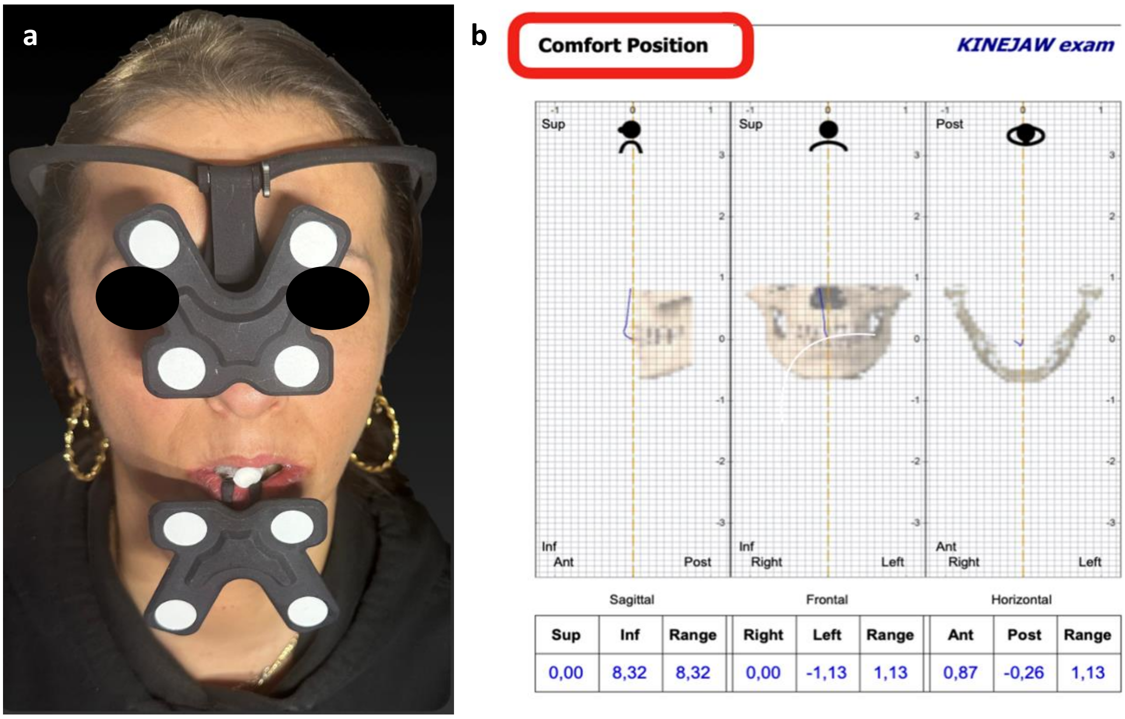

Fig. 5. *ITAKA Kinematic jaw exam execution (**a**) and related report on the comfort position (**b**).*

The authors advocate for an extemporary fabrication of a Lucia Jig, employed as a muscle de-programmer, in tandem with a digital capture of the mandibular range of motion. This approach enables a precise determination of the patient's comfort zone, wherein the centric relation is established. This process considers the VDO required to meet aesthetic and functional requisites, thereby defining a neurofunctional position that extends beyond mere anatomical considerations, usually defining centric relation.

Virtual planning phase

The dental laboratory was equipped with a detailed collection of diagnostic information, encompassing extraoral and intraoral pictures, digital models of both arches, a digital bite record, a facial scan, and a digital evaluation of the lower jaw's movements. This comprehensive dataset eliminates the necessity for conventional facebow registration by utilizing the facial scan as a critical reference point. This scan is used to accurately align the digital upper jaw model with the patient's cranial base, advocating for a facially driven approach in the planning and executing full arch implant-supported rehabilitations. Initially focusing on facial aesthetics ensures the restorative work is tailored to enhance the patient's overall appearance, subsequently guiding the prosthetic and surgical phases of treatment.

The provided data requirements to be matched for creating a virtual patient. The software of choice in the author's daily practice is Exocad (DentalCAD version 3.2) since it can handle all the planning and designing phases in a complete suite. 3D Standard Tessellation Language (.STL) files are uploaded and mutually registered using a dedicated wizard, including lower jaw kinematics. The next crucial step involves the integration of In-CAD Smile Design through the Smile Creator feature within Exocad. This tool transforms patient photographs into three-dimensional models, which can later be aligned with the 3D dental scan. This step serves as a double-check measure because any error in the data acquisition would be reflected in an incorrect 2D-3D matching and as a guide during the provisional fabrication.

Indeed, the next step is for the dental technician to start the fabrication of the first provisional, which won't be delivered before surgery but will be adapted when the post-operatory impression is sent so it can be delivered as fast as possible. This includes calculating the prosthetic space, derived by subtracting the freeway space from the VDO and determining the aesthetic space. A systematic review reports that 75%-100% of the upper front teeth are exposed during smiling (15). In contrast, another systematic review identified laypersons' preference for a slight coverage of front teeth crowns (16), placing the aesthetic space in the upper region at around 80% of the prosthetic space. The aesthetic space is crucial as it delineates the restoration segment visible during a smile and can be identified by the sustained pronunciation of the phoneme 'I'. However, this metric may vary and be tailored to accommodate the unique dental exposure observed in the patient pre-operatively.

In this specific patient, the dental lab digitally extracted residual hopeless teeth (used as index before) using the dedicated tool and proceeded with digital wax-up teeth positioning based on the aesthetic needs (Fig 6); once the distribution is accommodated on aesthetic, a simple tool can make slight changes to consider the previously acquired data on lower jaw movements to implement dynamic occlusion onto the newly created occlusal schema (Fig. 7). The result is a digital wax-up, that is confirmed by both the patient and the clinician.

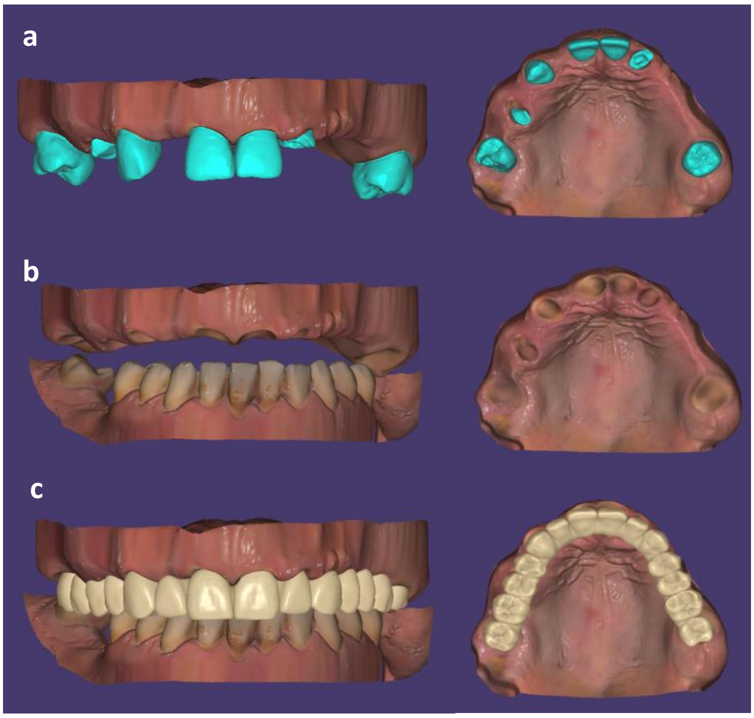

Fig. 6. *Hopeless teeth are marked (**a**) and virtually extracted (**b**). Aesthetic and static occlusion guide the initial positioning of denture teeth (**c**).*

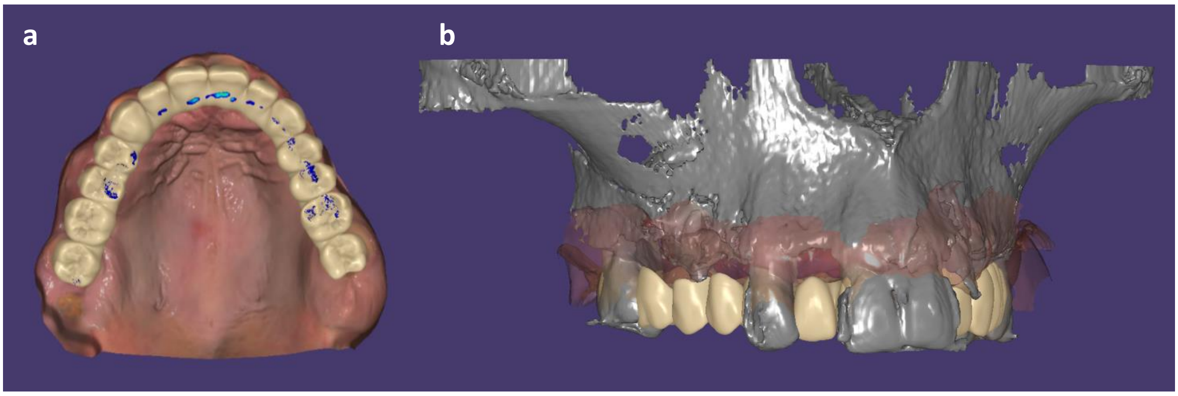

Fig 7. *Teeth are adjusted to dynamic occlusion (**a**), and the provisional project is finalized (**b**).*

The concluding steps of the pre-surgical process are timed. Ideally, all preparatory procedures, specifically the finalization of the digital wax-up, are completed one week before the scheduled surgery. This timeframe is crucial as it allows for necessary adjustments based on patient or clinician feedback. In the final week leading up to the surgery, attention turns to the design and fabrication of a customized prosthetic-surgical guide. This stent is peculiar in its design approach. Following the virtual extraction of the deemed hopeless teeth, save for the most distal ones, it is crafted to replicate the soft-tissue contours accurately.

The design is informed by the previously finalized provisional, supported by the palatine wrinkles, with strategic perforations aligned over the crestal bone where each prosthetic tooth, not implant, is to be placed (Fig. 8). The primary function of this surgical stent is not to direct the implant drills physically but to serve as a visual reference for the future dental prosthesis. This innovative approach allows the clinician to place implants with a prosthetically driven mindset, ensuring the implants' optimal position, the Low Profile Zimvie® abutments choice, and proper orientation for the planned restoration.

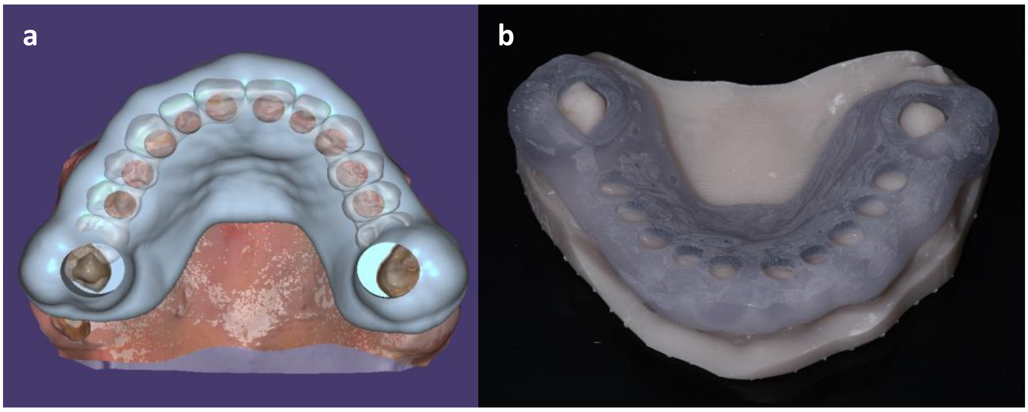

Fig. 8. *A prosthetic-surgical stent is designed according to the teeth's future position (**a**) and is 3D-printed for delivery on the day of surgery (**b**). Note the mucosal support given by the palatine wrinkles.*

In preparation for the surgery, a second template is crafted using digital design and 3D printing technologies - a custom individual impression tray tailored for easier data matching (Fig. 9). This template follows the previously outlined steps for the virtual extraction of hopeless teeth and the fabrication of a soft tissue-adapted stent, yet it introduces some additional feature. Firstly, the tray design incorporates an open top, allowing for the adequate placement of rigid impression materials, namely plaster. Additionally, the tray design extends over the palatine wrinkles since they are stable over time and unextensible, making it an ideal reference point for future data matching. Furthermore, a practical hand-hold is included, facilitating the device's manipulation and usage during the impression-taking step.

Fig. 9. *A digitally designed customized open-top impression tray extending over the palatine rugae.*

Implant surgery and provisional delivery

On the day of surgery, a full-thickness flap was elevated, with the initial crestal incision slightly decentred on the palatal side. The failing teeth, except for the distal ones, were extracted to allow the placement of the previously fabricated prosthetic-surgical stent (Fig. 10).

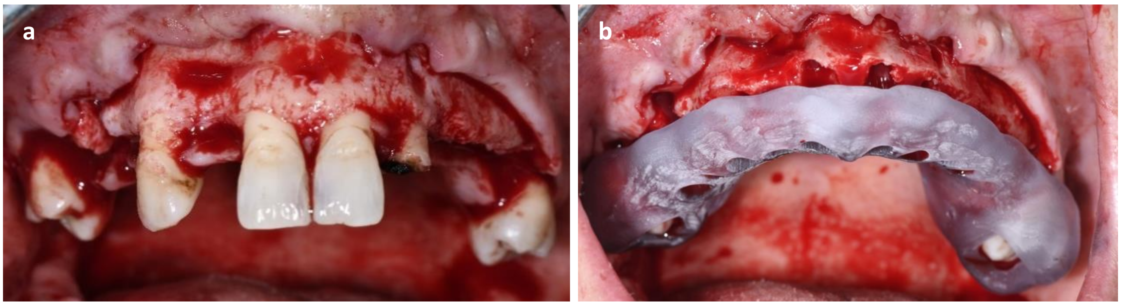

Fig. 10. *A full-thickness flap is raised (**a**), and the prosthetic-surgical glass-like template is placed after failing anterior teeth extraction (**b**).*

This template does not represent a static surgical guide but a pre-implant aesthetic guide. After that evaluation, tapered dental implant placement (T3® PRO, Zimvie Inc., Westminster, USA) in the premaxilla was possible, maximizing bone availability. Once the stent had fulfilled its role, it was removed, the distal teeth were extracted, and two tilted implants were positioned.

These posterior implants engaged the pterygoid lamina as part of the authors' usual implant positioning protocol for atrophic patients (17). Low-profile angled abutments were screwed in place, and grafting material (Endobon® Xenograft Granules, Zimvie Inc., Westminster, USA) was used to secure adequate marginal bone levels over time. Before suturing with single stitches using Vicryl® 3.0 (Vicryl® 3.0, Ethicon, Raritan, USA), healing abutments were secured in place.

As a final step, open-tray impression transfers were used in combination with plaster, polyvinylsiloxane, and the previously fabricated individual tray to obtain an immediate impression of the four anterior implants since the immediate load was not planned for the posterior pterygoid (Fig. 11).

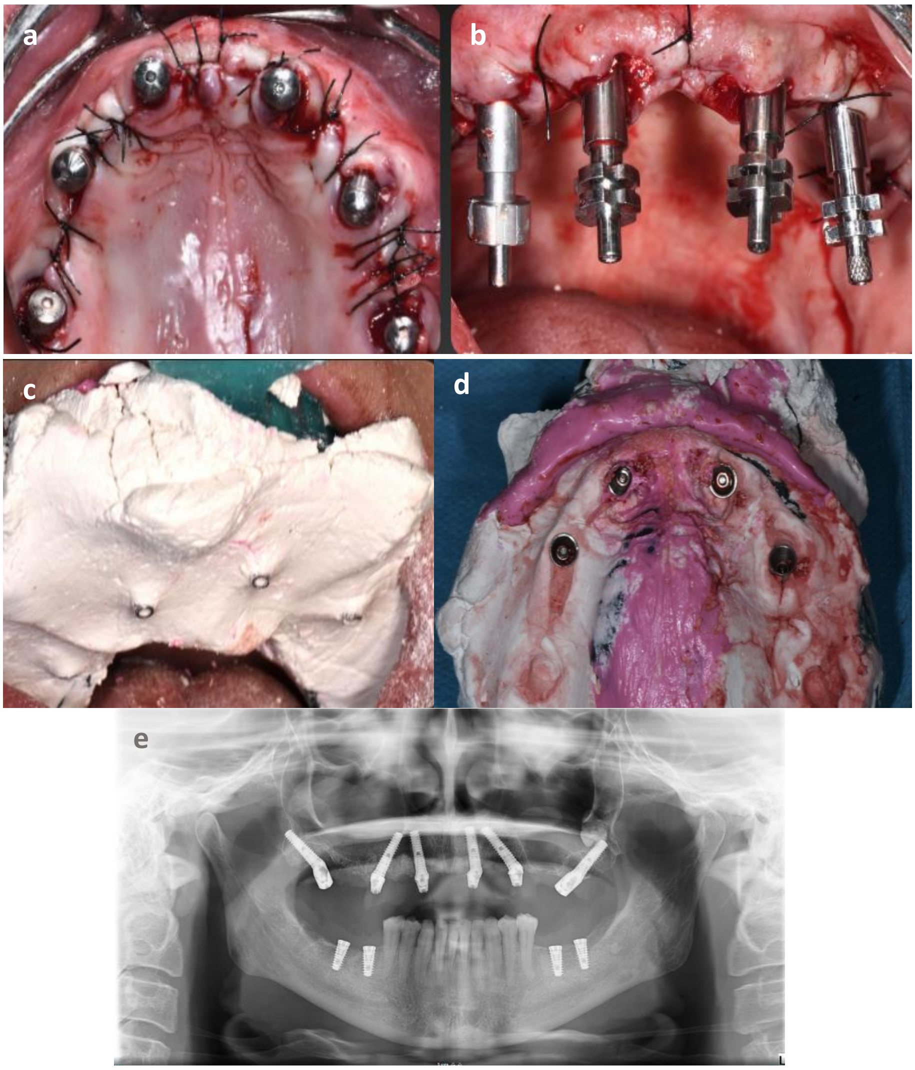

Fig. 11. *Implants and healing cups are placed, and sutures are positioned (**a**). A mixed plaster impression is taken with transfers positioned on the four anterior implants (**b**, c, and **d**) using a customized impression tray derived from the same aesthetic guide template and mucosal supported in the same palatine wrinkles reference area. The radiological Orthopantomography is scanned after the delivery of the milled Polymethyl Methacrylate (PMMA) provisional restoration screwed on 4 Low Profiles: let's note the radiolucent aspect depending on the absence of the armor (**e**).*

The patient is dismissed with post-operatory indications for a few hours. In the meantime, at the dental laboratory, the plaster impression cast is scanned using scan bodies, and the post-operatory data is aligned with the presurgical plan thanks to the palatine wrinkles, which are a stable reference point that allows for VDO maintenance (Fig 12).

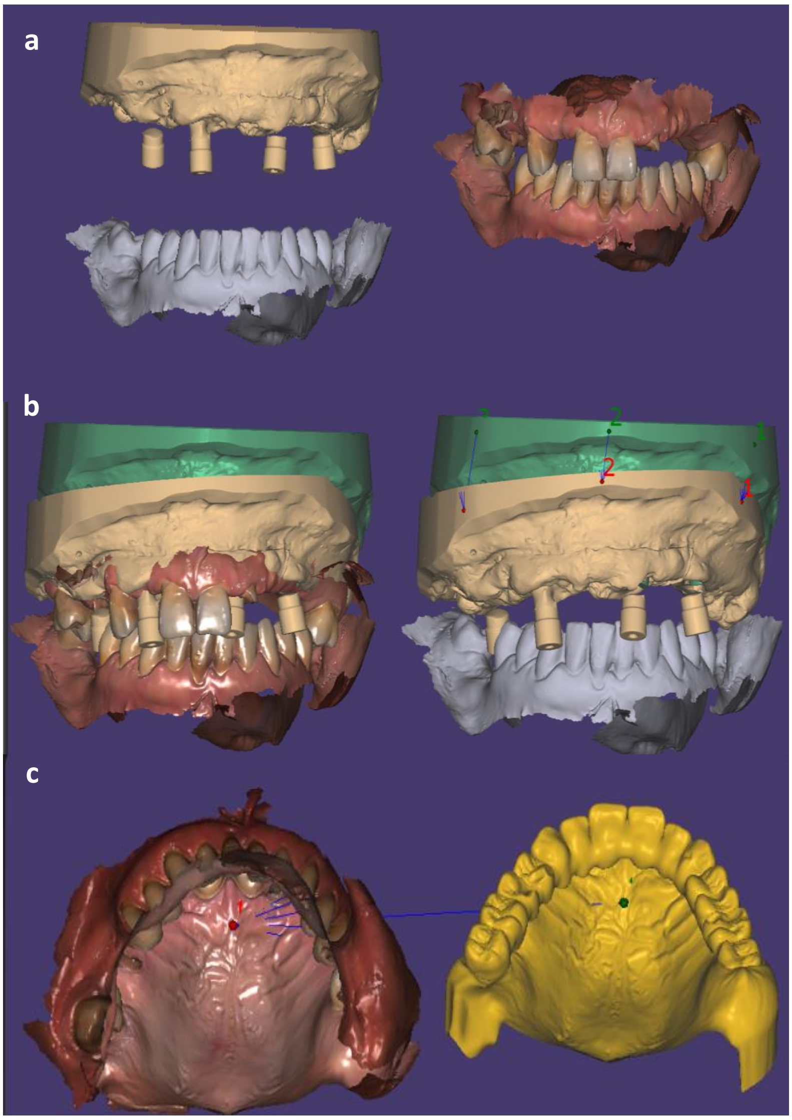

Fig. 12. *The immediate mixed impression is digitalized (**a**) using scan bodies and imported into the presurgical project (**b**). Palatine wrinkles allow for the data matching (**c**).*

Thanks to these newly gathered data, the dental technician matches the ScanBodies of the post-operative plaster cast digitalization with their digital correspondence. In the Authors’ experience, using higher offset ScanBodies allows for a more precise matching. Specifically, scan bodies with 6 matching references at the coronal level were employed (ScanBody ProCam, Biaggini Medical Devices srl, Arcola, Italy). Once this step is accomplished, the previously designed provisional can be adapted according to the newly established implant positions to accommodate holes slightly larger than the abutments (Fig. 13). The abutments will be luted with anaerobic cement, allowing maximum passivity.

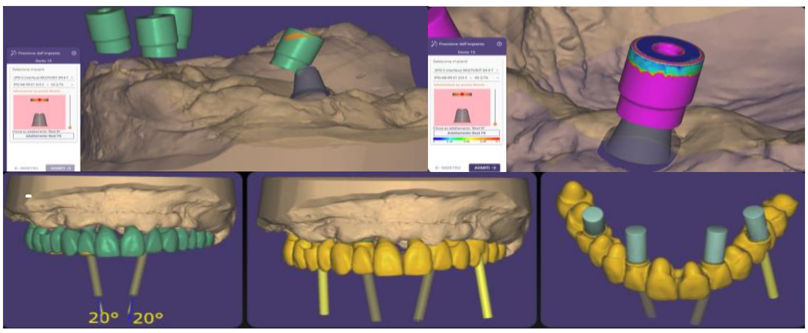

Fig. 13. *ScanBodies are precisely matched thanks to the coronal offset of the 6 reference points (**a**), and the previously confirmed digital mock-up is adapted (**b**).*

The resulting .STL file is sent to a 5-axis milling machine to obtain a long-lasting multilayer Polymethyl Methacrylate (PMMA) (Dentsply Sirona Inc., Charlotte, USA) provisional (Fig. 14); this material is chosen for its optimal mechanical properties, specifically an elasticity module greater than 2200 MPa and flexural strength greater than 80 MPa. The product is checked for passivity both digitally prior to the milling, thanks to a one-screw test, and on the original plaster cast. The provisional rehabilitation, loaded on four implants, is delivered within 24 hours, and minor occlusal corrections are made if necessary (Fig 15).

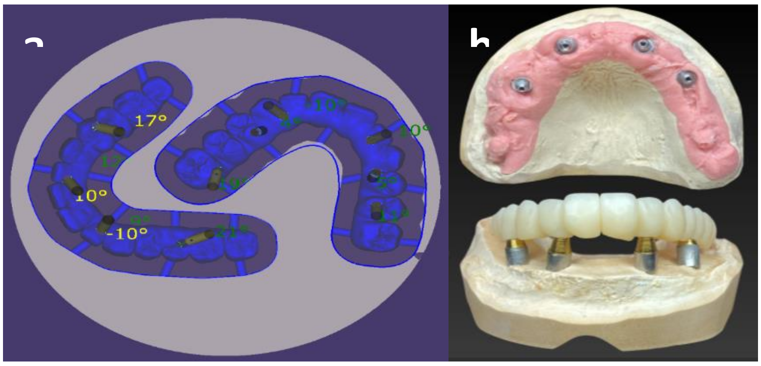

Fig. 14. *The provisional restoration project is sent to a milling machine (**a**), and the deriving product is checked for absolute passivity on the plaster cast (**b**).*

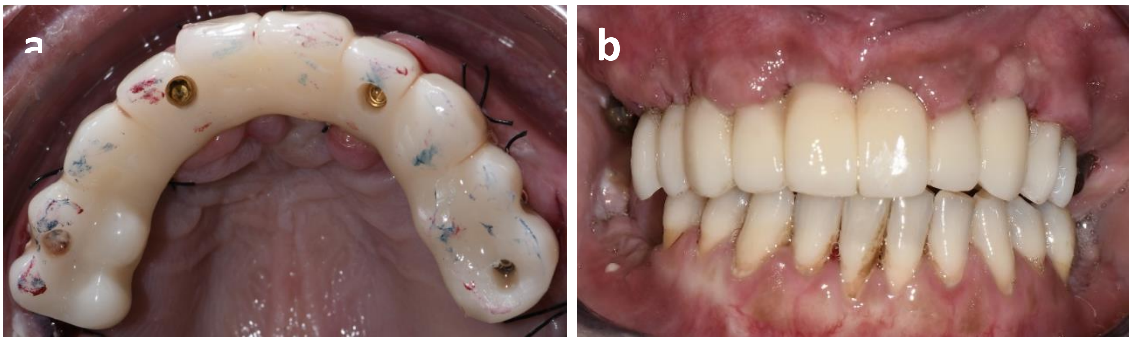

Fig. 15. *Contact points are refined intraorally (**a**), and the provisional is delivered within 24 hours of surgical intervention (**b**).*

Provisional re-evaluation

At the 3 months, the provisional needs to be re-evaluated, and further data must be acquired. While a detailed exposition of the fabrication process for a final full-arch implant-supported rehabilitation exceeds the scope of this document and has been comprehensively addressed in a recent publication by the authors (18), key steps will be outlined here to ensure a complete case presentation (Fig. 16).

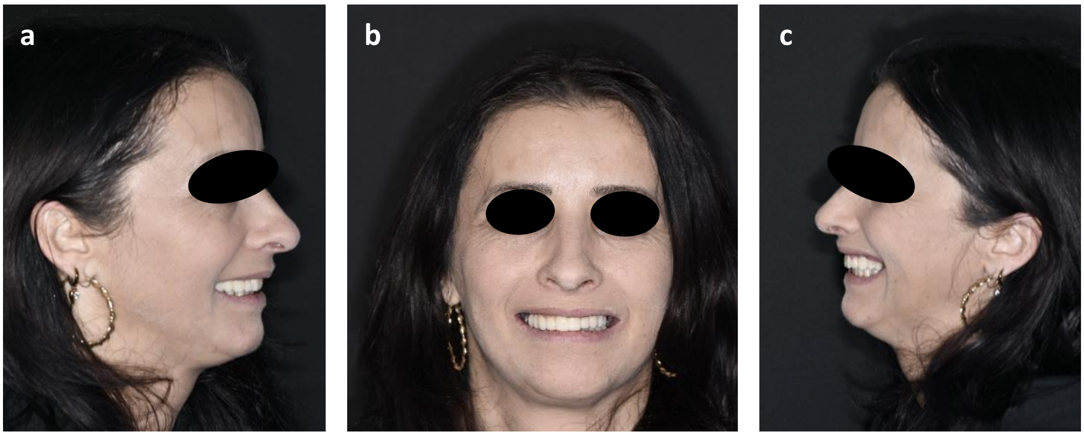

Fig. 16. *Front facing (**b**) and profile (**a**, **c**) smiling photos of the patient with the final restoration in situ.*

At this stage, the provisional is removed from the oral cavity, and intraoral ScanBodies (ScanBody ProCam, Biaggini Medical Devices Srl, Arcola, Italy) are positioned on the implants. The ScanBodies are interconnected using a pattern resin splint to ensure a highly accurate intraoral scan. This technique solidifies the ScanBodies as a single unit, stabilizing them to prevent any movement during scanning, which could compromise the precision of the data capture. Following the stabilization of the ScanBodies, a detailed intraoral scan is conducted. This scan captures comprehensive data on the soft tissues surrounding the implants and the solidarized ScanBodies, providing a precise digital representation of the mouth's current state. This data is further enriched by an extraoral scan of the provisional and an extraoral scan of the patter resin jig (Fig. 17).

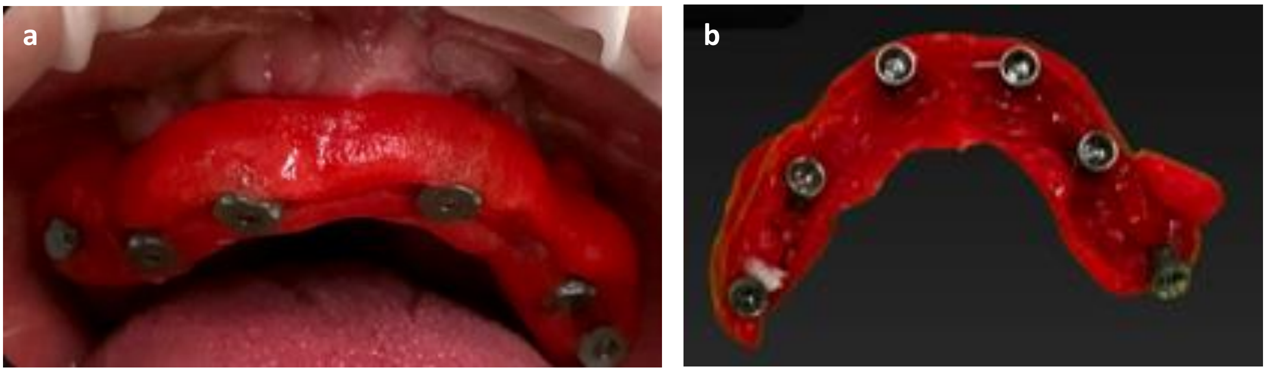

Fig. 17. *Thanks to pattern resin, ScanBodies are interconnected (**a**), and the jig is scanned intraorally and extraorally (**b**).*

A fundamental second step in this phase involves acquiring an extraoral scan of the worn provisional prosthesis and conducting a follow-up surface electromyography (Teethan®, Teethan S.p.A, Milan, Italy). This approach enables, after import in the CAD software, a detailed assessment of the functional wear on the provisional by comparing the.STL file from the scan with the initial CAD project. Such comparison aids in identifying any deviations or wear patterns that may have occurred during the provisional functionalization timeframe. Meanwhile, surface electromyography serves a dual purpose. It confirms the achievement of a balanced occlusion in the absence of prior pathological indicators. It assesses the impact of the rehabilitation process, especially if there were initial complaints or symptoms. Thanks to this data, the clinician and the dental technician can proceed with the final restoration fabrication.

DISCUSSION

In the conventional framework of implant dentistry, particularly when addressing full arch implant-supported restorations in failing or absent dentitions, a series of critical steps are indispensable for ensuring the success of the treatment. Among these, the accurate determination of the VDO stands out as a foundational requirement. This process, essential for both aesthetic outcomes and functional efficiency, varies depending on the presence of any remaining natural teeth. In cases where residual dentition persists, the assessment typically commences with measurements of the existing VDO. However, in scenarios where posterior dental contacts are missing, a meticulous registration of centric relation (CR) is performed to establish a base from which a new VDO can be evaluated.

This traditional method often necessitates the fabrication of an intermediate removable denture. While critical for assessing a suitable new VDO, this step introduces several challenges to the treatment timeline and patient experience. Firstly, it significantly prolongs the overall duration of treatment. Each phase, from the initial evaluation to the final loading of implants, is extended due to the additional steps required to fabricate and adjust the removable denture. Furthermore, this approach incurs higher costs attributed to the materials and labor involved in creating the denture and the extended clinical and laboratory work duration. Most notably, from the patient's perspective, this process mandates using a removable device from the moment of teeth extraction up until the placement and loading of implants. While necessary for determining the correct VDO, this interim solution may compromise the patient's comfort, aesthetics, and overall satisfaction with the treatment process. The necessity to adapt to a removable denture, even temporarily, can be a significant inconvenience, impacting their daily life and confidence.

Despite the benefits of digital technologies facilitating immediate loading protocols in edentulous arches, transferring occlusal information, namely VDO, from the removable provisional denture to the fixed one remains challenging due to the lack of reference points in edentulous impressions (19). The emerging digital workflow addresses these difficulties by minimizing the need for a physical interim denture for occlusal evaluation and exploiting digital techniques for data alignment and VDO transfer from initial assessment to post-operative restoration. In this context, hopeless teeth can be used as starting indexes for VDO assessment before extraction, thanks to the digital scans, if they still carry valuable information.

A notable advancement by Lorenzetti et al. (20) in 2021 introduced a method for fabricating an immediate load fixed implant-supported interim prosthesis for both arches without a removable denture, using palatine rugae as a reference point for the upper jaw. Lorenzetti's protocol still required analogic adjustments to the VDO and interocclusal relationship if necessary. At the same time, this proposed approach is based on fully digital evaluations, so no physical adjustment is required in the patient's mouth before taking the pre-operative impressions. A significant help in this direction is the implementation of both a face scan and a digital registration of the inferior jaw dynamics so that the most meaningful parameters are digitalized and joined into a single software. Palatine wrinkles are the chosen point of reference due to their inextensibility and stability over time, two mandatory features when identifying a fixed landmark; the data matching is indeed possible thanks to their presence both in the post-operative plaster impression and in the digital wax-up, eliminating reliance on mini-implants, which are poorly tolerated by patients and augment costs.

A second key element of the proposed approach is the retention of the most distal hopeless teeth during implant surgery. The specially designed stent can be accommodated with tooth support, which is much more precise than mucosal and less invasive than bone stabilization (21). This stent is defined as a prosthetic-surgical guide. Its focus is not to serve as a limiting guide to implant placement but rather to be a visual representation of the optimal teeth positioning, replacing the role of an interim denture with the benefits of no additional cost and little effort.

This workflow also highly emphasizes aesthetic considerations, starting from macroesthetic principles and extending to microesthetic considerations. The ability to create a virtual patient model by capturing a face scan and joining it with 2D photos in various settings makes it possible to analyze the dynamic aspects of facial expressions during social interactions within the dental laboratory. This analysis focuses on the proportions of the facial thirds, their alignment with the midline on the coronal plane, as well as the relationship of the maxilla to the skull base, and the VDO of occlusion on the sagittal plane. The virtual patient framework also facilitates the examination of the smile line and tooth proportions, enhancing the clinician's ability to communicate with the dental technician and the patient concerning the expected outcomes and aesthetic preferences, all without the need for creating a physical aesthetic try-in.

As the field evolves, the Authors anticipate an increasingly digital future for implant dentistry. Particularly for the discussed protocol and its variations, there's a push towards more accurate and streamlined digital scanning processes in full arch rehabilitations. Progress is evident with the introduction of dual-purpose impression abutments, designed to serve as transfer points for traditional plaster impressions and scan bodies for digital model casting. This innovation marks a significant step towards integrating and enhancing the precision of digital workflows in implant dentistry, bridging the gap between analogic and digital impression techniques.

CONCLUSIONS

This clinical report showed the efficacy of a mixed analogic and digital workflow in managing complex full-arch rehabilitation of the upper jaw. By employing a prosthetic-surgical guide and advanced preoperative digital planning, the proposed method facilitated the accurate transfer of crucial occlusal and aesthetic parameters from the initial assessment to the final restoration. Notably, this approach eliminated the need for traditional interim dentures to propagate the VDO of occlusion through different phases, exploiting the adequateness of digital scans in specific contexts and the traditional plaster impression, among others. This system significantly streamlined the treatment process, reducing treatment duration and costs without sacrificing the predictability of aesthetic and functional outcomes in complex cases.

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